OVERVIEW

Each year there are approximately 11,000 cases of spinal injuries that result in partial or complete paralysis. A significant portion of these cases are the result of sports related injuries that could possibly have been prevented with proper protection. The project undertaken was a preliminary analysis of the feasibility of a personal air bag spinal trauma protection device for mitigating spinal trauma due to bike/horse accidents.

For this project a mock torso was constructed from wood, instrumented, and dropped from a one-meter height both with and without an air bag, while impact accelerations were recorded. These experiments were then simulated using a finite element commercial code, ABAQUS/Explicit, with model updating.

The data from the experimental tests are provided for others to analyze. The ABAQUS input files are also provided. A description of the setup, testing, finite element analysis, and results obtained follows.

EDDIE DESCRIPTION

A model of the human torso was constructed for impact analysis. The major dimensions for the torso were determined by taking approximate width, height, and depth measurements of a 5' 10" male. Standard 2x4 and 2x6 pine lumber, ¼ inch plywood, wood glue and drywall screws were used to construct the torso. The torso was designed such that when dropped on it's "back" it would land on the protruding 2x6 that forms the "backbone" of the model. Figure 1 on the next page is a drawing of the model, followed by Figure 2, a picture of the actual model, which was nicknamed EDDIE (Eco-friendly Dynamic Device for Impact Experimentation).

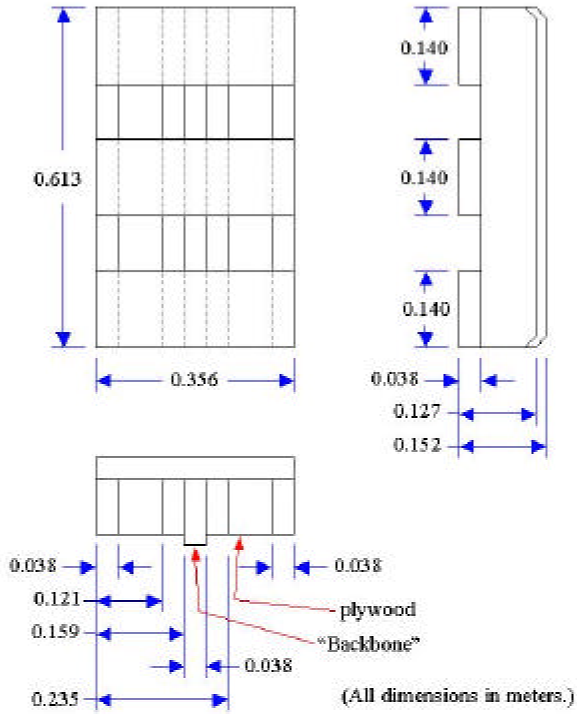


Figure 1. Drawing of EDDIE

Figure 2. Brian Stalcup with EDDIE Model

DROP TOWER DESCRIPTION

For impact tests on EDDIE, it was necessary to design a system that would allow the model to be suspended a minimum of one meter above the ground and provide a method for a clean release of the model during a drop. A wooden frame "drop tower", drawn in Figure 3 below, was designed and built from standard 2x4 lumber. The drop tower provided a 1.4 by 1.5 meter drop zone, and allowed for a maximum drop height of approximately 2.3 meters. EDDIE was suspended from the drop tower by nylon cord which, when cut, allowed EDDIE to drop and impact the floor within the drop zone.

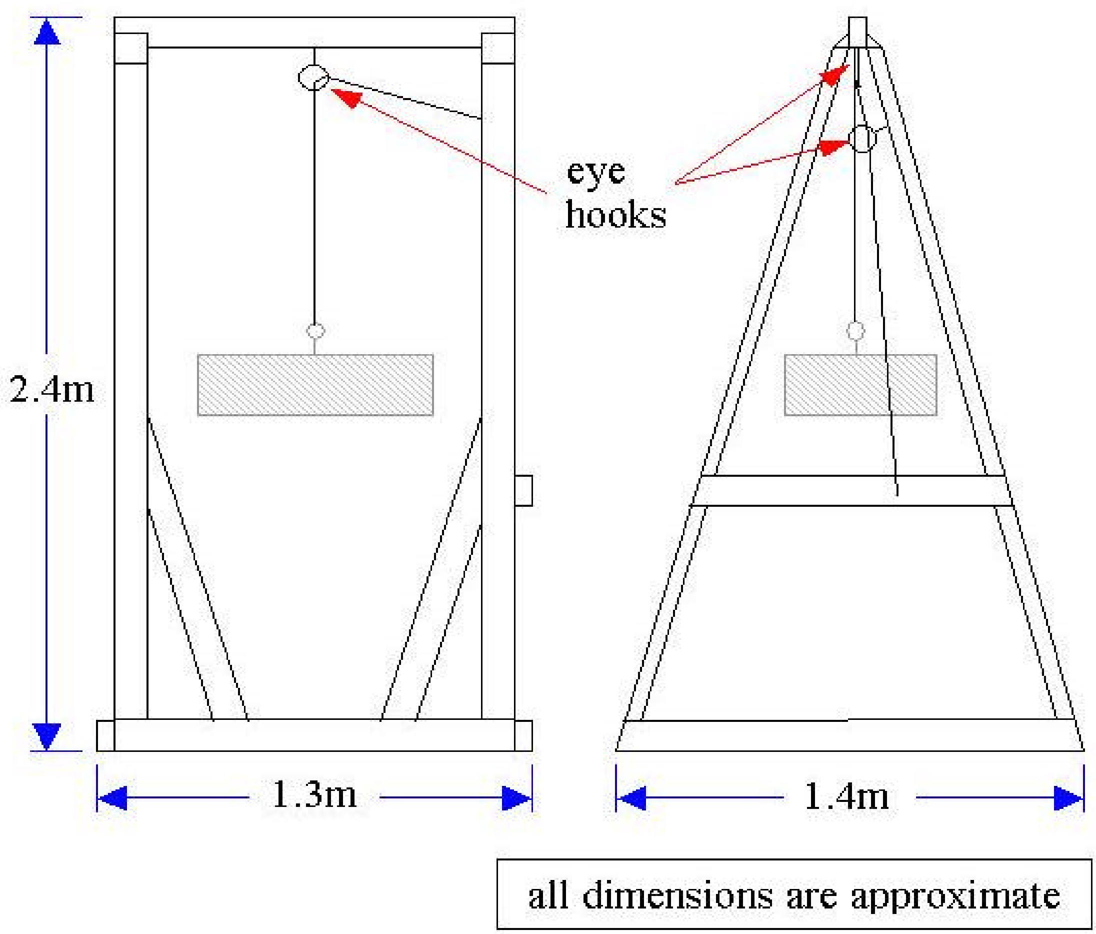


Figure 3. Drop Tower

AIR BAG DESCRIPTION

To mitigate the impact seen by the EDDIE model due to a one-meter drop, a "leaky" air bag device was constructed, and is shown below in Figure 4. The outer layer of the bag was constructed of a thin nylon material (blue). Stitched inside the nylon bag was a standard kitchen garbage bag (white) that formed the inner, air containing, layer. Deflated, the dimensions of the air bag were 25.4 cm by 58.4 cm. Inflated, the volume of the air bag was approximately 9,350 cubic centimeters.

The air bag was attached to the spinal cord of EDDIE with tape. Once EDDIE was hanging from the one-meter drop height, the bag was inflated and the open end of the garbage bag was taped closed. The air bag remained "leaky" due to the holes in the inner garbage bag lining where it was stitched to the nylon outer lining, and where the garbage bag was purposely not taped completely shut.

Figure 4. Impact Reducing Air Bag

TEST SETUP / DATA ACQUISITION

Preliminary estimates of the impact forces that EDDIE might see from a drop of one meter were calculated by hand. These estimates indicated that EDDIE might be subjected to accelerations over 1000 **g**'s. Therefore Endevco piezoresistive accelerometers (model 2264A-5K-R) with 5000 **g** ranges were used for instrumenting

EDDIE. As shown in Figure 5 below, EDDIE was equipped with four of this type of accelerometer. One of the accelerometers was determined to be malfunctioning, so only data from three accelerometers was kept from the tests. The accelerometers were attached to aluminum mounting plates that were hot glued to the model.

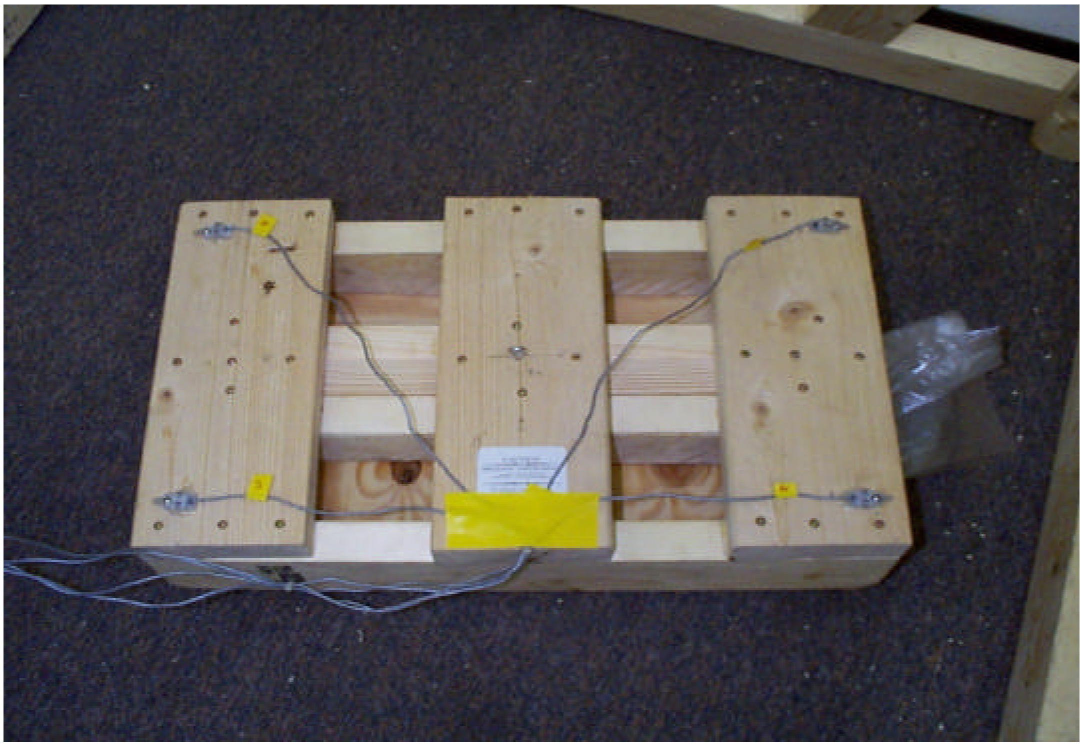


Figure 5. EDDIE Instrumented With Accelerometers

The three accelerometers were connected to a Measurement Division (model 2311) signal conditioner, with the voltage gain on the conditioner set at 10X. This conditioner was then connected to a Nicolet Data Acquisition System scope, which was running Odyssey, version 2.01, data acquisition software. The software was set to collect data at a frequency of twenty kilohertz. Figure 6 on the following page is a picture of the Nicolet System, as well as the signal conditioner (yellow). After calibrating the data acquisition system it was determined that the acceleration data collected needed to be multiplied by a factor of 7.5 to scale the data to the proper magnitude. This 7.5 factor was applied to the drop test data inside an Excel worksheet after testing was complete.

Figure 6. Nicolet Data Acquisition System and Signal Conditioner

EXPERIMENTAL PROCEDURE

Before any tests were performed, an experimental test procedure was prepared to specify the role of each group member during the tests in order to minimize confusion, make communication clear, and ensure safety.

A total of six drop tests were performed. Each test involved suspending EDDIE from a height of one meter by a nylon cord; then, on the signal of the data acquisition controller, logs were started on the recording scope and the nylon cord was cut, allowing EDDIE fall to the ground. Two tests involved dropping EDDIE with no "spinal cord" protection. Two other tests involved dropping EDDIE with the designed air bag attached to the spinal cord. The final two tests were also air bag tests, but instead of using a "leaky" air bag, the bag attached to EDDIE was simply an inflated garbage bag that was tied shut.

DATA FILES (html only)

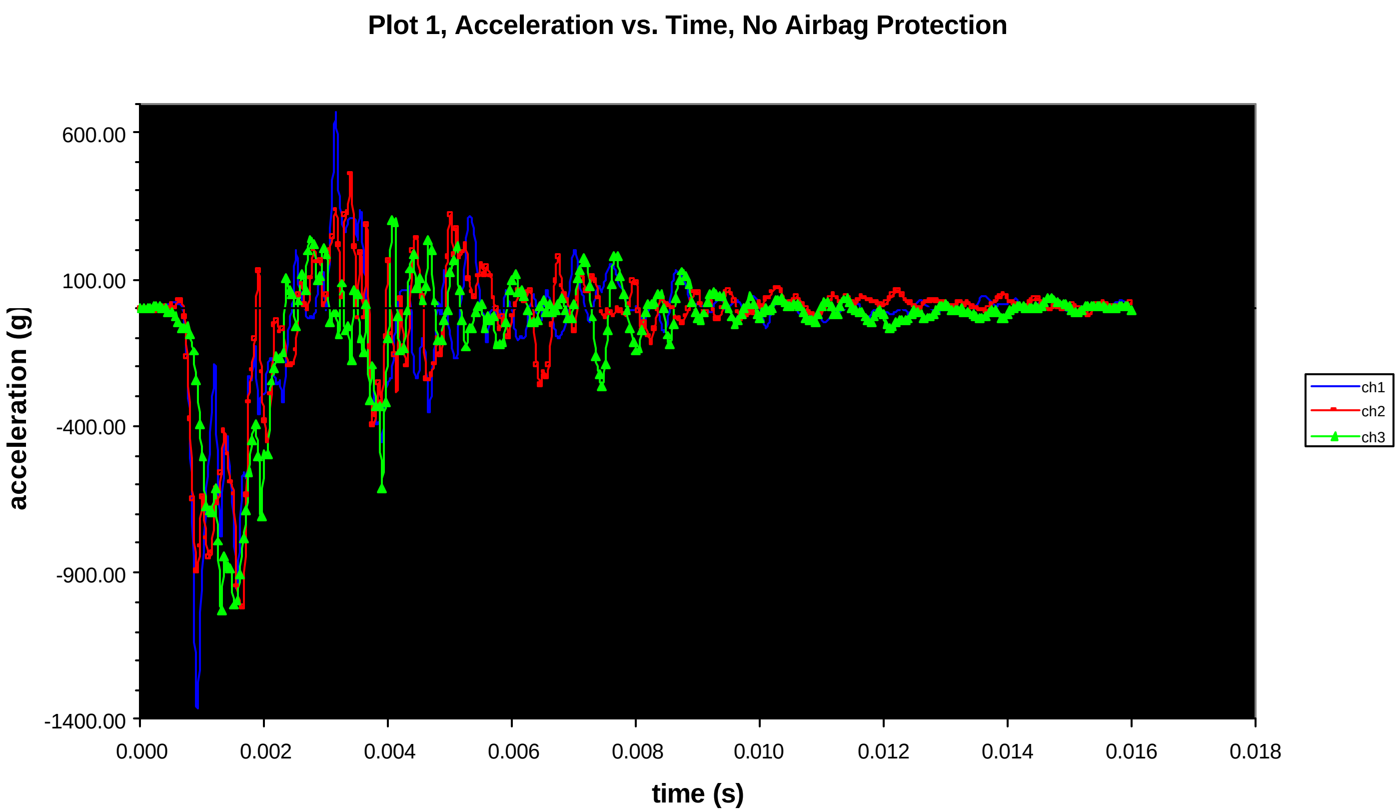
Below are six text files. These files contain the data that was recorded during the six drop tests that were performed.

eddrop_airbag_01.txt
eddrop_airbag_02.txt
eddrop_garbagebag_01.txt
eddrop_garbagebag_02.txt
eddrop_nobag_01.txt
eddrop_nobag_02.txt

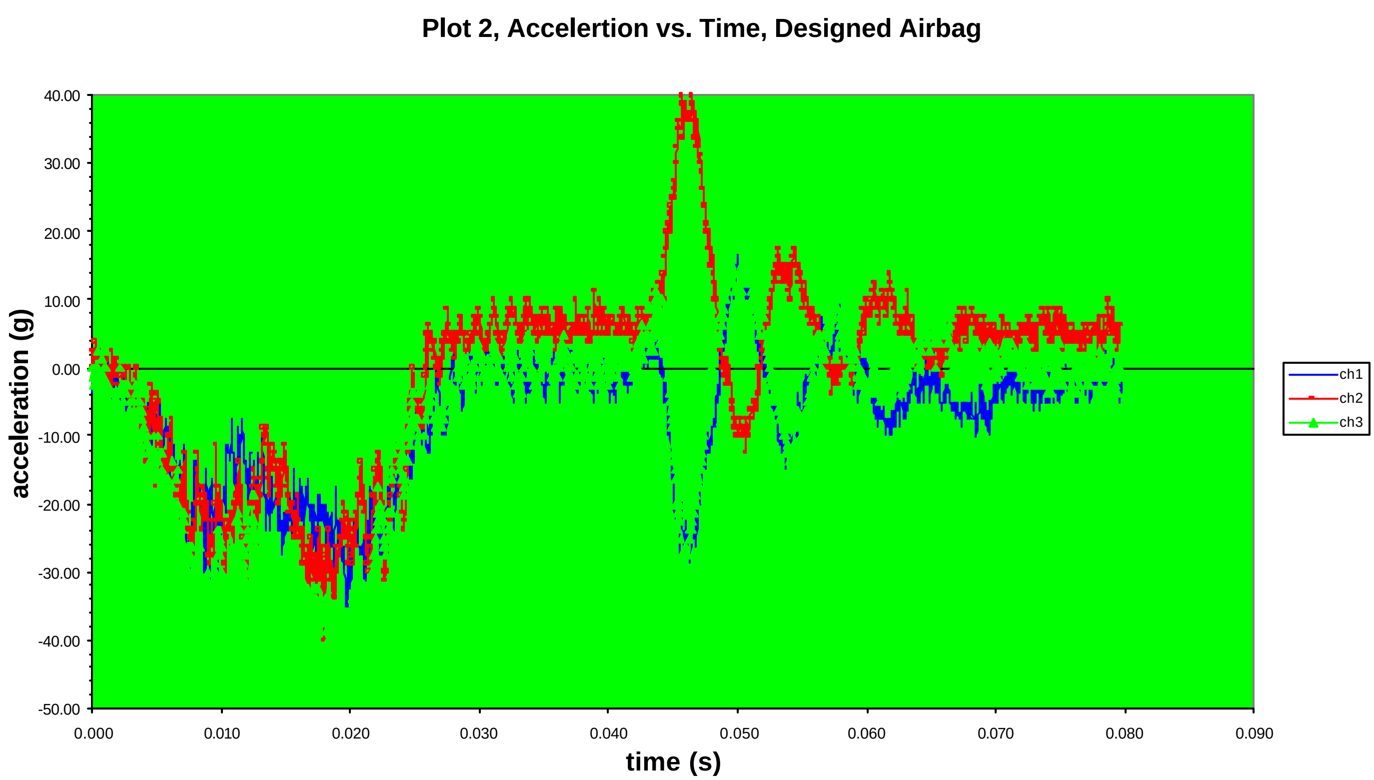
EXPERIMENTAL RESULTS

On the following pages are three plots representing the three types of drops that were performed. The plots show that the impulse time during impact for the drop with the designed air bag was about twice as long as it was for the drop without the air bag. This resulted in much lower accelerations during the air bag drop, and therefore EDDIE was subjected to much lower impact forces. The third type of drop that was performed was with a fully inflated garbage bag attached to EDDIE. Plot 3, from this test, indicates that an air bag that is not specifically designed to "leak" air out on impact is ineffective in dramatically reducing impulse time and impact forces.

Evidence that a properly designed air bag can significantly reduce impact forces can be seen in the following two plots. Plot 1 shows a maximum acceleration on the model of 1350 **g**'s on impact from a one-meter drop height. Plot 2 shows that the peak acceleration, from the same drop height, has been reduced to 50 **g**'s with the designed air bag installed on the model.

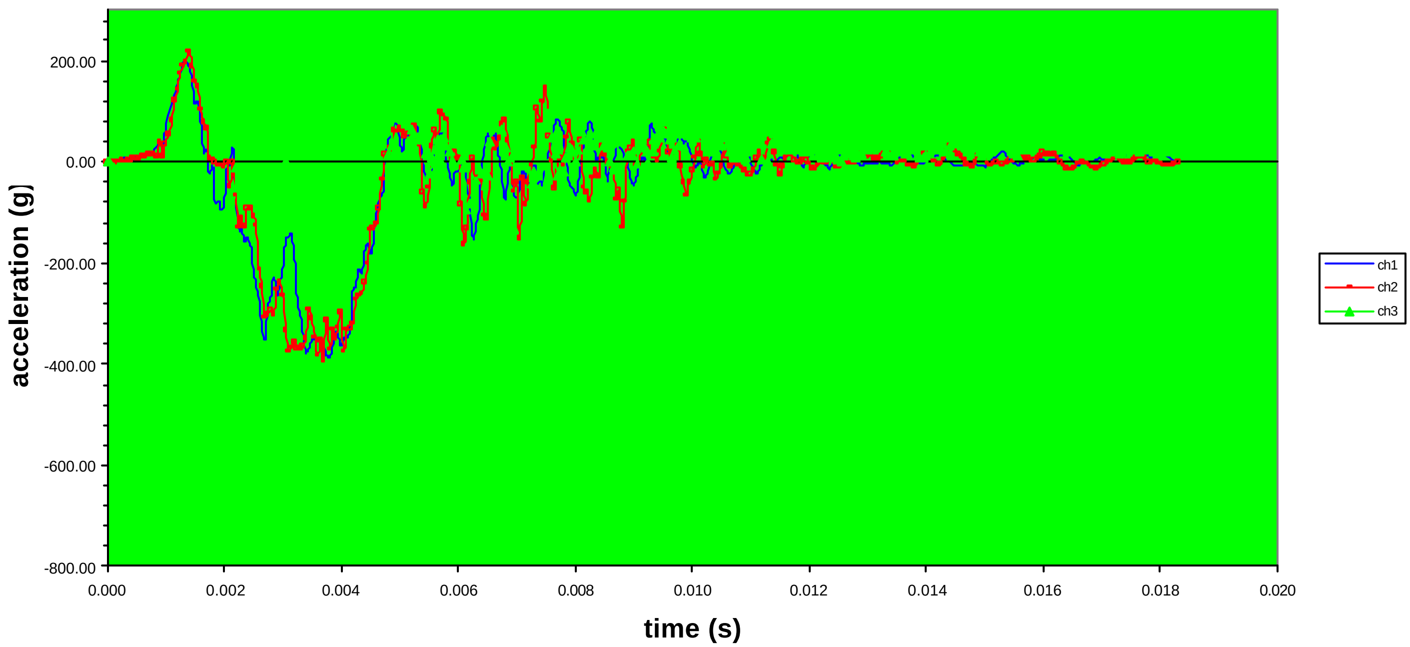


Plot 1, Acceleration vs. Time, No Airbag Protection
600.00
100.00
-400.00
-900.00
-1400.00
acceleration (g)
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
time (s)
ch1
ch2
ch3



Plot 2, Accelertion vs. Time, Designed Airbag
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
acceleration (g)
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090
time (s)
ch1
ch2
ch3

Plot 3, Acceleration vs. Time, Fully Inflated Garbage Bag Airbag



FINITE ELEMENT ANALYSIS INPUT FILES (html only)

Below are two text files containing the ABAQUS/Explicit input files for the finite element analyses performed. The first file contains the input file for the drop test analysis without the air bag. The second file contains the input file for the drop test analysis with springs and dashpots inserted to simulate the air bag.

edab.txt
eddrop.txt

FINITE ELEMENT ANLAYSIS

A finite element analysis (FEA) was performed to verify the experimental results from the drop tests. At first, the analysis was done to match the drops with no air bag. After that model simulated drops accurately, springs and dampers were added between the mock torso (EDDIE) and the floor to simulate the air bag. The geometry and mesh for EDDIE and the floor were constructed using the pre-processor Patran. The commercial code ABAQUS/Explicit was used to perform the finite element analysis.

The FE Model

The model was constructed with the same geometry as the physical model used in the drop tests. The finite element model has 19,959 degrees of freedom. This includes EDDIE, the floor, the carpet, and the air bag. Figure 7 below shows the finite element model.

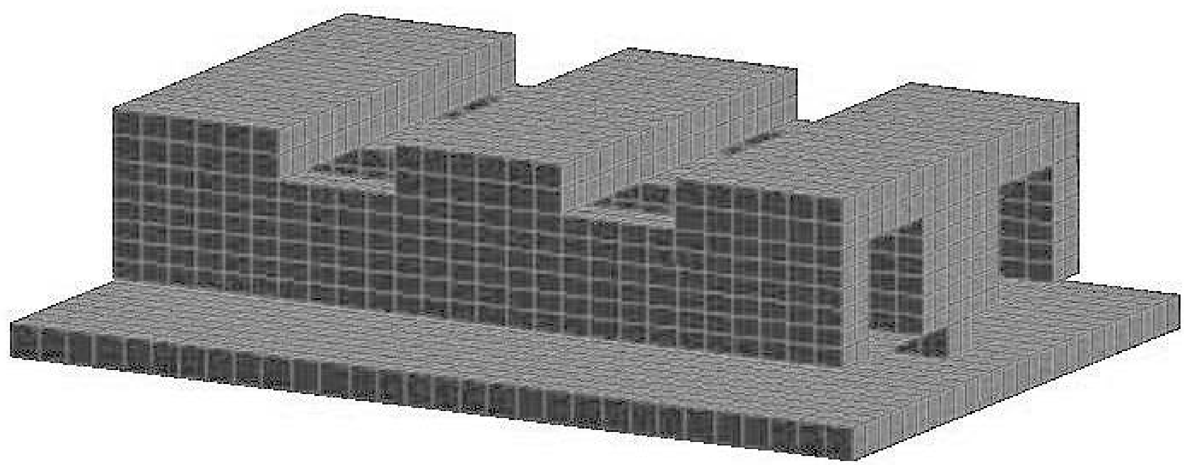


Figure 7. Finite Element EDDIE Model

EDDIE consists of 2,676 elements: 2,260 8-node linear brick elements and 416 4-node shell elements (which form the plywood). These elements were originally assigned property values corresponding to the wood used to build the physical model. Then these values were modified slightly to match the results from the model to the experimental results. The density was adjusted so the mass of the model was equal to the measured mass of the physical model. The Young's modulus of the wood was lowered to 0.4 GPa from the original value of 9.0 GPa. This significant lowering is due to the fact that EDDIE was made of several pieces of wood that were screwed and glued together. These added joints and surface contacts make the properties of the structure different from the properties of a single piece of material.

The floor in the model consists of two layers of elements, each layer being 26 elements by 30 elements, for a total of 1,560 elements. The top layer is made of 8-node linear brick elements, and the bottom layer is made of 8-node linear, one-way infinite elements. Infinite elements were used on the bottom layer to prevent wave propagation through the floor elements from interfering with EDDIE and altering the impact reactions. The floor elements were assigned material properties of concrete: Young's modulus = 25 GPa, density = 2,320 kg/m^3. Boundary conditions are applied to the bottom layer of nodes of the floor elements. They are constrained from moving in all three directions.

The carpet on the floor where the experimental drops were performed was simulated with dashpots in the finite element model. Dashpots were connected between each node along the "backbone" of EDDIE in the model, and the other ends of the dashpots were attached to the nodes on the surface of the floor directly below the "backbone". The damper values were determined by tuning the model to best simulate the experimental results.

FE Simulated Drop

To simulate the drop from one meter without the air bag EDDIE was given an initial velocity and positioned with the "backbone" touching the floor. The initial velocity was determined by equating 1) the kinetic energy after falling one meter due to gravity with 2) the potential energy before the fall. For the drop without the air bag the velocity at the time of impact is (2 * (9.8 m/s) * (1 m)) ^ (1/2) = 4.4 m/s.

The accelerations were recorded for the nodes representing where the accelerometers were attached to the physical model. The analysis without the air bag was run for 4 milliseconds. The plot of the average accelerations for the four nodes is shown in Figure 8 on the following page. Figure 9 shows the acceleration plot from the finite element analysis compared to the average accelerations from experimental drop test. The shape and maximum amplitude of the finite element curve very closely matches the experimental curve at the peak of the initial impact and the following rebound.

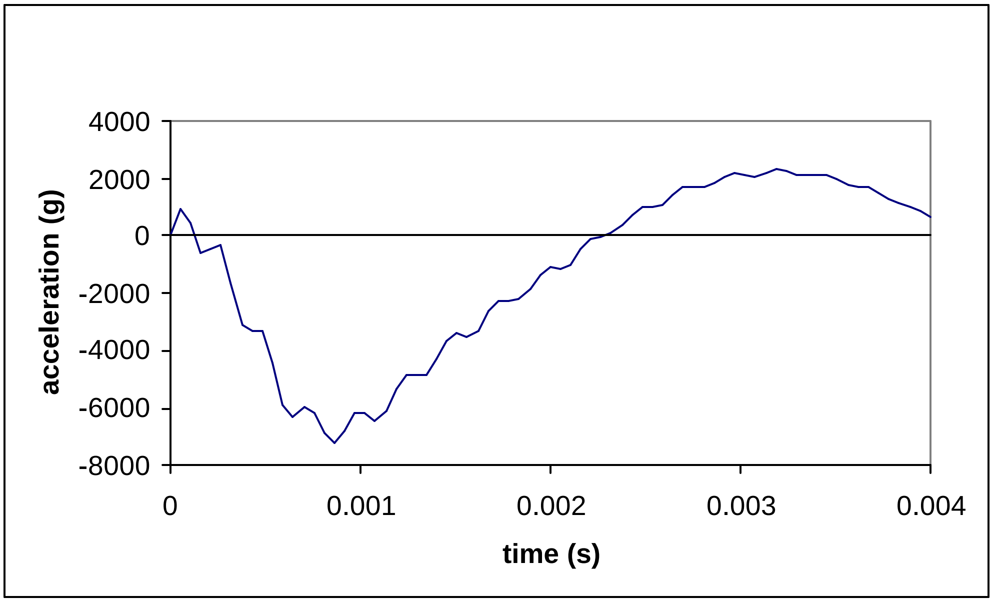


Figure 8. Average Acceleration of FEA Model, No Air Bag

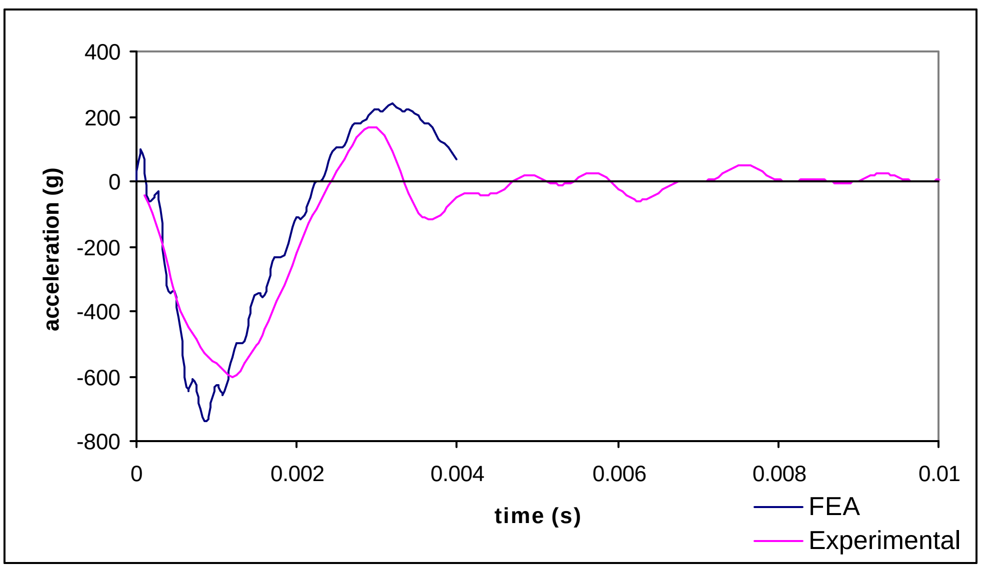


Figure 9. FEA Model Vs. Experimental Test

<u>FE Simulated Air Bag</u>

To simulate the drop with the air bag, EDDIE was moved away from the floor, and springs and dampers were added between EDDIE and the floor. In the model, EDDIE was raised 6 centimeters, which is approximately the thickness of the physical air bag. A spring element and a dashpot element were attached to each node on EDDIE's "backbone" and to the corresponding nodes on the floor surface. The damper values and spring constants were determined by again tuning the model results to the experimental results. The dashpot values were set to be a nonlinear function of the velocity so they would resist motion while the model was “falling” and not after impact. A plot of the average accelerations for the finite element model simulating the air bag compared with the experimental air bag test is shown below in Figure 10. The FEA and experimental acceleration histories don’t correspond exactly, but the average magnitudes of the first peak are close to the same. The impact times for the experiment and the FEA also match closely. To get better correlation, the spring and damper values in the finite element model need to be more finely tuned. With more time a more sophisticated air bag model could be developed.

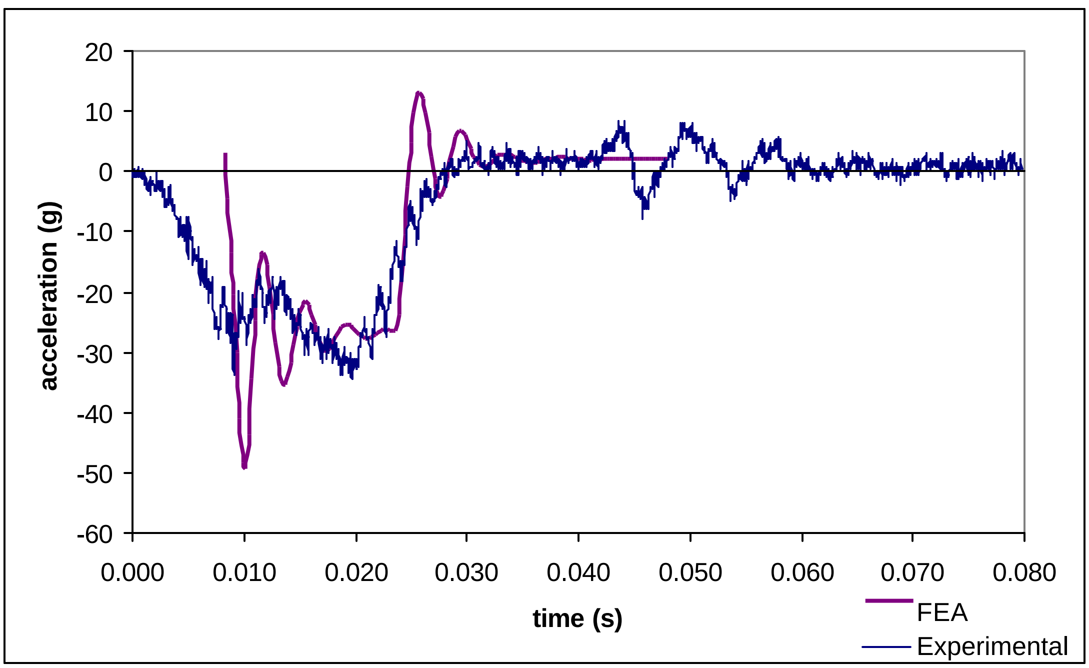


Figure 10. Air Bag FEA Simulation Vs. Experimental Test

CONCLUSION

The drop tests of EDDIE were successful in demonstrating that an air bag device can greatly reduce impact forces resulting from a fall. EDDIE was also successfully modeled in ABAQUS and with further modification the finite element model could be used to simulate a wide variety of drop tests including angled falls, falls with angular velocities, falls from higher distances, and falls onto other surfaces. This will be beneficial in analyzing new air bag designs and determining desirable properties of the air bag. Ultimately a prototype air bag system could be designed within ABAQUS and thoroughly tested before money is invested in building a physical prototype.